

Model system dynamics potential impact of disasters due to the re-period of the October 25th, 2010 earthquake in the Mentawai Islands

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Abstract. Geographically, the Mentawai Islands Regency has a territorial boundary with the sea. The north side is the Siberut Strait, the south side is bordered by the Indian Ocean, the east side is bordered by the Mentawai Strait, and the west side is bordered by the Indian Ocean. The Mentawai Islands Regency area has a high level of seismicity which makes it prone to earthquakes and tsunamis because it has an earthquake return period. Population and economic growth in the Mentawai Islands Regency continue to increase, resulting in a higher level of threat due to earthquakes and tsunamis to people and buildings. By using earthquake return period modeling based on secondary data and population and building growth modeling using system dynamics, Pentahelix can implement disaster risk mitigation in the Mentawai Islands Regency to reduce the risk of casualties and material losses. Based on the prediction that the Mentawai earthquake return period on October 25, 2010, will occur for 24 years to 57 years or around 2034 to 2067, and the results of system dynamics modeling with Powersim Studio 10 software, the number of vulnerable people affected is 24,764 people up to 42,944 people and potential losses. housing sector between 144.73 billion to 250.98 billion.

1 Introduction

Mentawai Islands Regency with Tua Pejat as its capital located on the west side of the West Coast of Sumatra Island. While geographically it is located at 0°55'00"–3°21'00" South Latitude and 90°35'00"- 100°32'00" East Longitude with an altitude of 0 - 4.00 m above sea level. The Mentawai Islands Regency is bounded: to the north by the Siberut Strait, to the south by the Indian Ocean, to the west by the Indian Ocean, and to the east by the Mentawai Strait [1].

Based on the Indonesian Disaster Information and Database (DIBI) issued by the National Disaster Management Agency (BNPB), the Mentawai Islands Regency has a Disaster Risk Index with a score of 197.20 or is included in the high-risk category for disasters, one of which is the earthquake and tsunami disaster [2]. The Mentawai Islands Regency has a high level of earthquake activity located on the island of Sumatra. Along the west coast of the island of Sumatra, especially the Mentawai Islands is an area that often experiences earthquakes with shallow depths. This is because the area is located on one of the peripheries of the active plate where there is an interaction between the Eurasian Plate and the Indo-Australian plate. This interaction produces a pattern of subduction or subduction and the Mentawai fault zone [3]. As a result of the earthquake, the Mentawai Islands Regency area also has a potential tsunami threat, 3 (three)

Villages/Kelurahan have a high tsunami hazard level and 11 (eleven) Villages have a medium tsunami hazard level [4].

The unique feature of the Mentawai Islands area is characterized by the presence of a seismic gap zone which is a historical earthquake area in 1797 with rupture zones throughout the Mentawai Islands and 1833 which occurred in the southern part of the Mentawai [5]. The high coupling condition in the Mentawai gap zone has not been released by significant earthquakes around this area such as the 2007 earthquake, the Padang earthquake magnitude 7.9 in 2009, and the Mentawai earthquake magnitude 7.8 in 2010 [6].

Several earthquakes with magnitude > 6 also occurred in the eastern area of Siberut Island with an upward fault mechanism associated with the Mentawai back thrust (MBT) so that the effect of these earthquakes on the Mentawai segment needs to be investigated further. The Padang earthquake in 2009 was an intraslab earthquake with an oblique mechanism [7]. The depth of the relocation earthquake was 87.6 km and approached the relocation result which was 90.0 km [8]. The strike-slip movement of the oblique Indo-Australian plate is accommodated by the Sumatran fault and the Mentawai fault in the eastern area of the Mentawai archipelago [7,9–11]. Meanwhile, the interpretation shows that the existence of a back thrust structure in the eastern Mentawai is the result of the analysis of reflection seismic

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data and bathymetric data. Back thrust with a length of more than 300 km has a strike almost parallel to the Sunda subduction and a westward slope [9].

The results of the relocation in this study showed that several earthquakes around the MBT structure continued to a depth of 20-30 km and several earthquakes had an upward fault mechanism with a dip of about 60° which was following the interpretation results [9].

Until now, the time of the earthquake cannot be predicted, but on the other hand, several studies can explain that the return period of earthquakes can be estimated. The estimated return period of an earthquake with a magnitude of 5 – 8 SR in the Mentawai Islands region has a different return period, which is around 0.4633 to 150.5033 years with details [3] in Table 1.

Table 1. Calculation of Earthquake Return Period

Magnitude (SR)	Return Period (Years)
5,0	0,463
5,5	1,214
6,0	3,185
6,5	8,351
7,0	21,895
7,5	57,404
8,0	150,503

Table 1. Explains that the October 2010 earthquake with a magnitude of 7.2 on the Richter scale, will have a return period of 22 years to 57 years. The Mentawai Islands Regency is an area that should be wary of because there is stored energy (energy of expectation) that can be released at any time in the form of a large earthquake. The last largest earthquake occurred on October 25, 2010, measuring 7.2 on the Richter Scale, centered in South Pagai [3]. The comparison of the location of the analysis of the location of the earthquake on October 25, 2021, BMKG and several international institutions is shown in 0

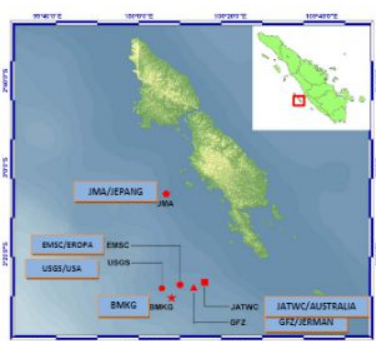


Fig. 1. Comparison of Main Earthquake Analysis Results from BMKG and Several International Institutions [12].

The Mentawai earthquake, October 25, 2010, was a repetition of the same event that had occurred in 1797 with a magnitude of magnitude 8.7-8.9 and within the range of its outbreak, an earthquake of magnitude 8.9 - 9.1 occurred in 1833 [13,14]. Table 1 shows that the return period for the Mentawai earthquake on October 25, 2010, is estimated to be around 22 years to 57 years or from 2032 to 2067.

Based on data and information from the BNPB Command Post and the Center for Operational Control for Disaster Management in West Sumatra as of November 22, 2010, the earthquake and tsunami caused 509 deaths, 17 people were injured, and 11,425 people evacuated, which are spread over refugee points in South Sipora District, South Pagai District, North Pagai District, and Sikakap District. The number of houses damaged as many as 1296 units with details of damage to 879 housing units heavily damaged, 116 housing units moderately damaged, and 274 housing units lightly damaged, with a total loss of 348.92 billion while the loss to the housing sector was around 115.82 billion (33.2%) [15]

Disaster risk assessment is an approach to show the potential negative impacts that may arise as a result of an existing potential disaster. This potential negative impact describes the potential number of lives, property losses, and environmental damage exposed to potential disasters. In conducting a disaster risk study, the functional approach of the three parameters forming the risk or risk of disaster, namely Hazard or threat, Vulnerability or vulnerability, and Capacity or capacity related to disaster [16].

$$R_{isk} = H_{azard} X \frac{V_{ulnerability}}{C_{apacity}} \tag{1}$$

R_{isk} : Disaster Risk (2)

H_{azard} : Disaster threat (3)

$V_{ulnerability}$: Disaster Vulnerability (4)

$C_{apacity}$: Disaster Management Capacity (5)

Disaster risk in the Mentawai Islands Regency can increase, one of which is due to the threat of an earthquake return period and an increasing population which also increases the number of vulnerable people and population density. In law number 24 of 2007 article 55 paragraph 2 mentions vulnerable groups, namely infants, toddlers, children, pregnant and lactating mothers, people with disabilities, and the elderly. To reduce the risk that occurs, the government of the Mentawai Islands Regency by increasing the capacity, for example by structural and non-structural mitigation.

The data on the population of the Mentawai Islands in the BPS document of the Mentawai Islands Regency, in 2010 was 76,173 people and increased to 92,021 people in 2019. Population growth in the population of the Archipelago Regency has a crude birth rate of 1.17, a crude death rate of 0.22%, a migration rate entry of 1.20%, and an out-migration rate of 0.43%. The age grouping of the population can be done based on the age structure, grouped into 3 (three) major groups, namely: Young people, namely the population aged under 15 years, or the age group 0-14 years. The productive age population is the population aged 15-64 years. The elderly population, namely the population aged 65 years and over, follows the WHO provisions. The percentage of the population in the Mentawai Islands Regency under the age of 15 years is 25.9% and the elderly is 6.61% [18].

Data on the population of the Mentawai Islands Regency from 2010 to 2019 is in Table 2.

Table 2. The population of Mentawai Islands Regency from 2010 to 2019.

Year	Total Population
2010	76.173
2011	77.078
2012	78.511
2013	81.840
2014	83.603
2015	85.295
2016	86.981
2017	88.692
2018	90.373
2019	92.021

Source: [17]

The population of the Mentawai Islands Regency in 2010 was 76,173 people until 2019 as many as 92,021 and the percentage of vulnerable population in 2018 was 32.51%. The urgency of this study is the use of vulnerable population parameters in determining the purpose of this study to simulate the number of vulnerable residents and housing that could potentially be affected if there was a return period of the October 25, 2010 earthquake using system dynamics modeling.

2 Method

The data used in this study is based on the secondary data. Secondary data is a source of research data obtained by researchers indirectly through intermediary media. This means that the researcher acts as a second party because it is not obtained directly. The secondary data has been collected including the population of Mentawai regency from 2010 to 2019 (Mentawai Islands Regency BPS) and data from the earthquake return period from previous research. Data analysis method modeling system dynamics population growth of Mentawai Islands Regency is used to determine the number of vulnerable people affected and the amount of potential loss to the affected housing sector in the event of an earthquake return period. The software used to model the system dynamics of the potential threat of the Mentawai Islands earthquake return period is Powersim Studio 10.

The assumptions used in model making and model simulation are as follows: (1). The average number of people per house is 4 people (2). The percentage of heavily damaged houses is 5% (3). The percentage of moderately damaged houses is 3% (4). The percentage of lightly damaged houses is 2% (5). The value of the loss of a large damaged house is Rp. 100.000.000 per unit (6). The value of the loss of a moderately damaged house is Rp. 60.000.000 per unit (7). The value of the loss of lightly damaged houses is Rp. 40.000.000 per unit.

3 Result and discussion

3.1 Simulation and model accuracy

After the problem is understood and modeled into the Causal Loop Diagram (CLD), the next step is to simulate the system that has been poured into the CLD diagram model, input into the Stock Flow Diagram (SFD) using Powersim Studio 10 software. Total the population used in this model is the total population of the Mentawai Islands Regency in 2010-2019, used to determine the development of the population in 2020-2068. After simulating the model of the relationship between population growth and the potential for earthquake and tsunami disasters, Stock Flow Diagram (Fig. 2), it is necessary to test the accuracy of the simulation model to determine the level of model validity. The accuracy test is carried out using a simple error test, namely the Average Mean Error (AME) of the population. During the accuracy testing period is adjusted to the actual data, which is in the period 2010 to 2019. Fig. 2. Flowchart or Stock Flow Diagram (SFD) Simulation results of population growth in the Mentawai Islands Regency from 2010 to 2019 are in Table 3.

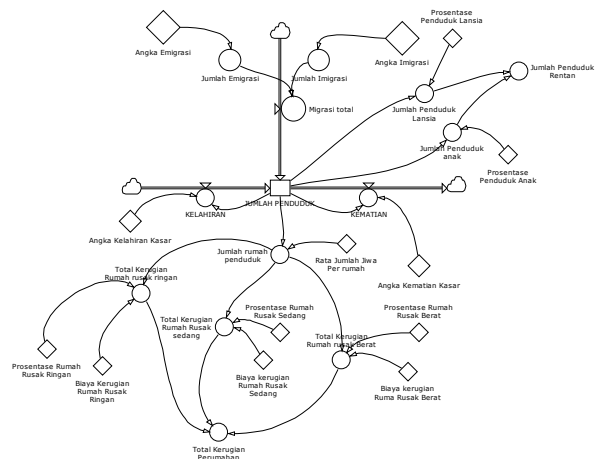


Fig. 2. Flowchart or Stock Flow Diagram (SFD)

Model validation is an attempt to conclude whether the system model is valid in representing the reality being studied, which lead to convincing conclusions. Validation in this study uses the AME value as an indicator that the model made is valid. The AME value is obtained through the equation:

$$AME = \frac{|Ds-De|}{De} \times 100\% \tag{6}$$

Information :

$$Ds = \text{Average between simulation results} \tag{7}$$

$$De = \text{Average between reference results} \tag{8}$$

A model is considered valid if it has a maximum value of AME 0.5%. To get the AME value, reference data and simulation data are needed which are shown in Table 3.

Table 3. Reference Data and Simulation Data on the Population of Mentawai Islands Regency from 2010 to 2019

Year	Total population (Reference Data)	Total population (Simulation Data)
2010	76.173	76.173
2011	77.078	77.483
2012	78.511	78.806
2013	81.840	80.141
2014	83.603	82.850
2015	85.295	84.101
2016	86.981	84.223
2017	88.692	85.610
2018	90.373	87.010
2019	92.021	88.423
Average	84.057	82.221

The reference data were obtained from the population data of the Mentawai Islands Regency from 2010 to 2019 issued by the Mentawai Islands Regency BPS, while the simulation data was obtained from a dynamic model using the Powersim Studio 10 program. actual and simulated have the same value as many as 76,173 people. The actual data on the population in the period from 2010 to 2019 has an average of 84,057 people, this number does not show much difference and is almost the same as the average from the simulation results, which is 82,221 people.

$$AME = \frac{|82.221 - 84.057|}{84.057} \times 100\% = 2,18\% \quad (9)$$

Based on the actual and simulation data, the results of model validation with an Average Mean Error (AME) between the two resulted in a figure of 2.18% so that the model was declared valid and could be used for further analysis.

3.2 Forecast of vulnerable population and total housing sector losses

Estimates of the number of vulnerable people and the total loss of the housing sector with a population growth model simulation are made until 2068 using a dynamic system model. From the results, it can be seen in Table 4 the predictions of the population generated by the years 2032 to 2068.

Table 4 shows that if the return period of the earthquake occurs in the range of 24 years to 57 years or occurs in 2034 to 2067, the potential for vulnerable populations to be affected is in the range of 24,764 people to 42,944 people, for the estimated loss to the housing sector between 144.73 billion up to 250.98 billion.

The potential disaster risk for housing sector losses due to the earthquake return period in the Mentawai Islands Regency increased from 115.82 billion in 2010 to 144.73 billion to 250.98 billion. Therefore, it is necessary

to take mitigation measures against earthquake and tsunami disasters by implementing structural and non-structural mitigation.

Table 4. Simulation of the Number of Vulnerable Populations and Total Housing Loss for the return period in 2032 to 2068

Year	Total population (Person)	Vulnerable Population (Person)	Housing Losses (Rp)
2032	76.173	24.764	144.728.700.000
2036	81.489	26.492	154.828.827.361
2040	87.010	28.287	165.318.263.502
2044	92.743	30.151	176.212.014.304
2048	98.698	32.087	187.525.664.052
2052	104.882	34.097	199.275.397.724
2056	111.304	36.185	211.478.024.148
2060	117.974	38.353	224.151.000.046
2064	124.901	40.605	237.312.455.010
2068	132.095	42.944	250.981.217.436

Structural mitigation such as the construction of Giant Walls, Earthquake Resistant Houses, Green Belts, construction of evacuation routes, and others. Meanwhile, non-structural mitigation such as RTRW policies with a disaster perspective, prohibition of building houses in earthquake and tsunami-prone zones, increasing disaster knowledge through education and training programs.

4 Conclusion

The October 2010 earthquake disaster has a potential return period between 24 years to 57 years or will occur in the range of 2034 to 2057.

The results of modeling the potential return period of the October 2010 earthquake will threaten the population vulnerable to 24,764 people up to 42,944 people and potential housing losses between 144.73 billion to 250.98 billion.

To reduce the impact of disasters due to the return period of the earthquake and tsunami are doing by conducting mitigating both structural and non-structural.

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